SP222 Experiment: Faraday's Law

Purpose To demonstrate Faraday's Law of Induction using a "flip coil" and a bar magnet passing through a coil of wire.

Reference Tipler, Physics (4th edition)

Introduction According to Faraday's Law, whenever the magnetic flux f_{m} through a circuit changes, that change "induces" an electromotive force E in the circuit. The magnitude of the emf is equal to the time rate of change of flux, and the direction of the emf and of any current that results from it is such as to oppose the change of flux. In symbols, Faraday's Law is stated

$$E = -\frac{d\varphi_m}{dt} \qquad (1)$$

where the magnetic flux f_{m} through the surface S bounded by the circuit is given by

$$\varphi_m = \int_S \vec{B} \cdot \hat{n}\ dA = \int_S B \cos\theta\, dA$$

As this last equation implies, φ_m can change because B changes, because œ changes, because the area A bounded by the circuit changes, or because any combination of these changes occurs. Motional Emf's arise when the some element of the circuit moves. Pure induction occurs when the magnetic field varies with time, and the resulting emf is associated with a non-conservative (circulating) electric field. The electric field in a region of space circulates if and only if the magnetic field in that region is time dependent.

$$E = \oint_C \vec{E} \bullet d\vec{\ell} = -\frac{d\varphi_m}{dt} = -\frac{d}{dt}\int_S \vec{B} \cdot \hat{n}\ dA = -\int_S \frac{\partial \vec{B}}{\partial t} \cdot \hat{n}\ dA$$

A flip coil is a planar, multi-turn loop of wire that may be rotated about an axis in the plane of the coil. If the flip coil is placed in a magnetic field and rotated, the magnetic flux through it changes, and an emf is induced. If a coil with N turns and area A is placed in a uniform magnetic field of magnitude B, and is flipped just once (so that the flux through the coil changes from its maximum positive value to its maximum negative value), emf is related to the rate of change in flux by Equation (1) above. Separating variables and integrating gives

$$\left| -\int E\, dt \right| = \left| \int d\varphi_m \right| = \left| \Delta\varphi_m \right| = 2NBA$$

Thus, if the on the left is measured, the strength of the magnetic field may be determined.

If a bar magnet passes through a fixed, stationary coil, the magnetic flux will first increase as the magnet approaches the coil, reach a maximum when the magnet is halfway through, and finally decrease as the magnet leaves the coil. Because the induced emf is related to the rate of change of flux, the emf will exhibit a bipolar, "two-lobed" appearance: it will be zero when the magnet is far from the coil, go positive (for example) as the magnet approaches, pass through zero again when the magnet is halfway through the coil, go negative as the magnet leaves the coil, and finally return to zero when the magnet is once again far from the coil. The amplitudes of the positive and negative excursions should be equal and will depend upon the number of turns N and area A of the coil, the length and strength of the magnet, and the speed with which the magnet passes through the coil. Whether the emf goes positive or negative as the magnet enters the coil will depend upon the way the voltmeter is connected and also upon whether the magnet approaches the coil with its North or South pole leading.

Task: Characterize the effects above as either motional and induction emf's.

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Procedure

Part I. Setup

(1) Verify that your computer is displaying the USNA Physics Laboratories screen. Click on the icon labeled Two Chan Plot&Read. After about a minute, the startup screen will appear.

(2) Using the controls at the upper left-hand corner of the screen, select a positive trigger slope and a trigger level of about 0.0005 V. Also, select the most sensitive voltage range for Channel 1, a sampling rate of about 10 kHz, and about 1000 samples per channel.

(3) Open Data.Editor. Then you can use the pull-down Window menu to switch back and forth between Two Chan Plot&Read and Data.Editorwhenever you wish. Switch back to Two Chan Plot&Read for now.

Part II. Measure the Earth's magnetic field with a flip coil.

(1) Connect the leads from the flip coil to Channel #1 of the USNA Physics Department Interface Box. Face northward, holding the flip coil in front of you, with one handle in each hand and with the plane of the coil oriented horizontally.

(2) Click on the Read/Plot button, and quickly but smoothly rotate the coil through one or two complete revolutions about the horizontal axis that passes through the handles. In just a moment, a graph of the emf induced in the coil should appear on the Two Chan Plot&Read screen. If it does not, the software probably did not trigger. Check the trigger settings and the connections, and try again, perhaps rotating the flip coil a bit more quickly. If you continue to have difficulty, check with the instructor.

(3) Adjust the voltage range, samples per channel, and sampling rate until you get a graph that looks good. If the graph appears excessively "noisy", try adding a small capacitance in parallel with the flip coil to smooth the signal. Experiment! Try to use 300 points or less if you can get good data with this restriction.

(4) Once you have a good plot, print out a copy and save the data in a file. Switch to Data.Editor. Read in the file you just saved. Use the integration function (Ú y dx) to find the integral of the emf over the time it took you to flip the coil once. Set the limits on the integral by noting that the emf is zero when the magnetic flux has its maximum positive or negative value: therefore, to integrate between positions of maximum flux, you should integrate between successive zero values of the emf. Using the numerical value you obtain for the integral, and the known values of N and A for the coil, deduce the magnitude of the Earth's magnetic field. Estimate the uncertainty in your result.

Part III. Investigate the passage of a bar magnet through a coil of wire.

(1) Disconnect the flip coil from Channel #1 and replace it with the ends of the wire that is wrapped around the glass tube.

(2) Switch back to Two Chan Plot&Read. Hold the glass tube nearly vertically, click on the Read/Plot button, and quickly release a small bar magnet so that it slides through the tube and the surrounding coil. A graph of the induced emf should appear on the Two Chan Plot&Read screen. Adjust the voltage range, samples per channel, and sampling rate for best appearance. Print the final graph.

(3) Repeat the measurement several times. Investigate how the magnitude of the induced emf depends on the number of turns of wire and the speed of the magnet as it passes through the coils. Study how the sign of the induced emf depends upon which end of the magnet passes through the coil first. Make prints of the associated graphs. Write a few sentences describing your results and how they agree with the predictions of Faraday's Law.